MOSAICC: An inter-disciplinary system of models to evaluate the impact of climate change on agriculture;

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ABSTRACT

Climate change potentially threatens the livelihood of many people who depend on local food production. Information from different disciplines has become an essential to estimate and predict the impact of climate change on local food production. However, data is often scattered and specifically focused on one scientific domain. Therefore, the FAO in partnership with European research institutes developed a web-based interactive toolbox (called MOSAICC) which integrates climate scenarios with crop growth simulations, hydrological modeling and economic predictions on a national level. In the first (alfa) version of the toolbox, all models are interconnected in terms of input and output, and can be accessed through a web interface. The models are chosen because of their generic nature and low data requirements. However, the toolbox needs testing, as not all questions regarding the model use and integration have been addressed yet. The real innovation of the overall project lies in the socio-technical integration and contextualization of domain-specific information in an interactive learning process of the different users. The toolbox should be regarded as a common pool of knowledge, accessible by all stakeholders (e.g. scientists, policy makers and civilians) as an integral part of an interactive, participative and interdisciplinary decision making process regarding e.g. land-use planning or climate mitigation measures. Therefore, the MOSAICC toolbox is a novel, agile and versatile adaptive management support systems, combining state-of-the-art technologies with aimed at empowerment and participation.

INTRODUCTION

Climate change poses a great challenge to agricultural productions systems, potentially threatening those who particularly depend on local food production for their livelihood. Information on the impact of climate change is a primary requirement for policy makers to cope with climate change. In recent years, scientists have developed a range of different models that monitor, evaluate and predict the effect of climatic change. However, information on e.g. climate, local economy or different areas of the environment like groundwater resources and hydrology, is often scattered among scientists, policy makers or civilians. There is a growing awareness that agro-environmental sustainability is a complex interaction between socio-cultural, economic and biophysical systems (Matthies et al. 2007). Therefore, an innovative multidisciplinary approach combining all knowledge from the different domains would be an ideal tool to evaluate the resilience of our agricultural systems.

The Food and Agriculture Organization of the United Nations (FAO), in partnership with European research institutes, has developed an integrated suite of models for assessing the impact of climate change on agriculture at a national level. The MOdelling System for Agricultural Impacts of Climate Change (acronym: MOSAICC) is based on a generic methodology defined to assess the impact of climate change on agriculture, covering climate data downscaling, crop yield projections, water resource estimations and a economic model, The economic model is a Computable General Equilibrium model (CGE) aimed at modelling the impacts of changing in yields on the economy at national level. All models are connected through a common spatial database architecture and interconnected in terms of input and output. All models and databases are platform independent and can be hosted on a central server. Multiple users can access the MOSAICC toolbox simultaneously through a common web interface, making data exchange easier, transparent and more efficient for the users.

MOSAICC is unique and innovative as it combines a web-based interactive and integrated modelling environment together with tools and materials for capacity building and technology transfer to (government) institutions and scientists. The specific design allows for inter-disciplinary working groups to stimulate cooperation and foster knowledge exchange. Currently, the MOSAICC toolbox is under validation in Morocco and will be implemented afterwards in other countries.

This paper gives an overview of the inner workings of the MOSAICC toolbox. However, the innovation of the MOSIACC toolbox lies in the socio-technical integration of the whole project. Therefore, an exploratory discussion is provided on the different aspects of the project and their prospects for further development.

MATERIALS AND METHIDS

Description of the system

The assemblage of the MOSIACC toolbox is based on a generic methodology defined to assess the impact of climate change on agriculture, including statistical downscaling of climate data, crop yield projections, water resources estimations and economic modeling (figure 1). Low resolution (typically 250 km) climate data serve as primary input for the whole model structure. These datasets feed the hydrological and crop models, which need information on elevation, land cover and soil. The outputs of these models serve subsequently as input for the economic impact assessment. A short description is provided on the different modules.

Statistical downscaling portal for climate data

The climate scenario predictions are produced using observed weather time series combined with global climate models (GCM). The coarse resolution of the GCM need to be downscaled to make them applicable for the regional or country scale. A statistical downscaling tool (Confiño et al. 2007) is used based on the DAD (Data Access and Downscaling) tool. This tool allows for downscaling large scale predictors of data on precipitation and minimum and maximum temperature to a set of weather stations, provided that enough observations are available.

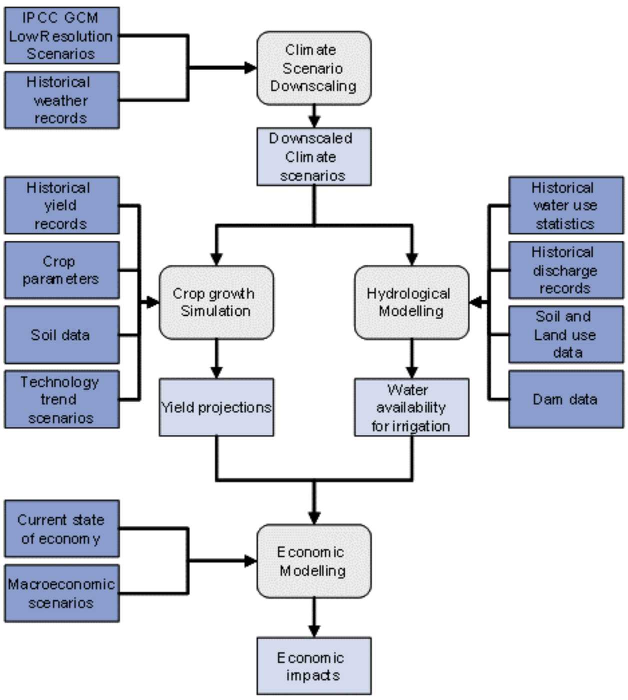

Figure 1: a schematic description of the MOSAICC model integration organized in four main components (white boxes), their inputs (blue boxes) and outputs (light blue).

Crop growth simulation

Two different models were selected to estimate the crop yield. The first model is called WABAL, which was designed to simulate the soil water balance at crop level. Basically, it's a vertical soil profile, with no explicit spatial extent. It is usually used at the level of agro meteorological stations, pixels or cultivated areas. The model requires a minimum number of inputs (10 daily) on precipitation, evaporation, soil water holding capacity, soil holding capacity and crop parameters. Variables like water satisfaction index (which is the fraction to which the water requirements of the plants are met) for water surplus or deficit and actual evapotranspiration are the outputs. The second model is AQUACROP (Hsiao et al. 2009, Raes et al. 2009, Steduto et al. 2009), which was developed at FAO. This model simulates the crop response to water in a more sophisticated way. AQUACROP requires crop parameters (i.e. data on crop physiology, cultivars, management) that are much more sophisticated and more difficult to acquire than the ones needed for WABAL**.** A distinction is made between crop transpiration and soil evaporation, but also root development and canopy cover can be simulated. Crop Water stress (when the soil water content drops below the upper threshold), biomass production and yield estimates are part of the output. Furthermore, CO_2 concentration in the atmosphere can be taken into account. The selection between WABAL and AQUACROP depends on the availability and detail of climate information at country level.

Hydrological modeling

The Spatial Tools for River basins and Environment and Analysis of Management options (STREAM) (Aerts et al. 1999) is a grid-based spatially-explicit distributed water balance model that describes the hydrological cycle as a series of storage compartments and flows. It was originally designed for river basin studies with an emphasis on water management aspects. The original version has been successfully applied at spatial scales ranging from small sub-basins (e.g. Notebaert et al. 2011) through medium to large basins (e.g. Krishna (Bouwer et al. 2006); Zambezi, (Winsemius et al. 2006); Meuse (Ward et al. 2008, Ward et al. 2011); up to the (sub-)continental and global scale (Aerts et al., 2006; Renssen et al., 2007; Ward et al., 2007). STREAM calculates the water balance per time-step (user-defined, typically 10 – 30 days) for a spatially distributed gridded landscape. The model requires information on precipitation, temperature, land cover, soil type, depth and elevation. From temperature data the actual and potential evapotranspiration are calculated using the Thornthwaite (1948) and Thornthwaite et al. (1957) equations, respectively. MOSAICC uses the open source version of STREAM; this version presents the advantages to handle direct data on evaporation and to integrate dams, and has an automatic calibration procedure. Furthermore, a new procedure for flow accumulation has been implemented in this version of STREAM.

Economic modelling

The economic modelling part comprises a Dynamic Computable General Equilibrium model that simulates the evolution of the economy based on variations in crop yield projection, inspired by Löfgren et al. (2001) and Thurlow and van Seventer (2004). The model allows the user to define multiple activities producing one commodity. To allow for spatial variations, commodities can be produced by different activities. The CGE is based on activities, commodities and regions. Data from other models are aggregated before entering the CGE. The model accounts for different crops as well as differentiated crop yields across the country. The effect of crop yield variations is simulated using a shift parameter in the activity production functions. The model provides estimations for all the endogenous variables (e.g. commodity prices, imports, taxes, household income and savings etc.). A set of input ('benchmark") including values of all these variables at a given time is used to calibrate the model. Then when shocks are simulated using the exogenous variables (changing crop yields for example) these variables get new values (output). The effects of changing yields can be assessed by comparing benchmark and "shocked" situations. Climate change can affect agricultural production. First, yield changes predicted by one of the crop models (WABAL or AQUACROP) are passed on to the economic model through exogenous shocks to a technical shift parameter in the production function. Changes in the availability of irrigation water predicted by the STREAM model are passed to the economic model through an exogenous decrease of the water endowment

Utilities

A number of utilities have been developed to manipulate the data, facilitating their transfer from one model to another. An interpolation tool has been developed using AURELHY (Bénichou and LeBreton 1987) or kriging methods to interpolate data. A second tool calculates evapotranspiration using the method inspired by Hargreaves and Samani (1985) (instead of the Thorntwaite calculations) and can directly be applied on interpolated rasters. The beginning and the length of the rainfed growing seasons can be estimated using a tool called PLD and extracted from AgroMetShell (Hoefsloot 2005), the FAO crop yield forecasting software. Calculations in PLD are based on precipitation and evapotranspiration (Cocheme and Francquin 1967). Finally, some GIS tools to manipulate spatial data are also available in the system.

MOSAICC has been developed as a server-side web-based application. All the software is installed on a unique server together with a common database. Data and simulations are managed through web interfaces. This architecture has several advantages. Firstly, the users do not need to install any software on their working stations; they just need an internet connection and a web browser to run simulations. Secondly, this architecture allows remote access and sharing data on the servers thanks to the database. Thirdly, dedicating a server with good performances to the sole use of MOSAICC helps to reduce computing time. Finally, updates and bug fixes can be done quickly and easily at the server side, without any intervention of the user.

The modules and software on the MOSAICC server are without license costs or completely open source. Open Source means that the source is openly accessible to everyone, but also promotes free redistribution, allows modification and derived works. All modules are platform independent and can thus also be installed and run on closed source operating systems and environments. The toolbox is set up to be an open architecture where models could be added or modified rather easily. Models can be substituted as long as protocols for data exchange are followed and model assumptions are compatible.

The web-based interface (front-end) of the MOSAICC toolbox contains an interface to the different models and allows the user to upload and download relevant data. The parameters of the different modules can be specified and user documentation is available for help. The front-end was built using a content management system, which allows for the relatively easy managing of large numbers of users and facilitates administrative tasks.

The backend contains a range of different technologies such as Apache, PHP, Mapserver and Drupal; and different libraries such as PROJ4, GEOS, GDAL and GDAL-Python. Programming languages used are C /C++, Pascal, Basic, Fortran, Python and R. The database management system consists of a PostgreSQL database with a PostGIS extension.

RESULTS

The MOSAICC toolbox is still in a development stage, and no in-depth testing has yet been carried out. The alfa version of the interface is shown in figure 2. The interface is divided into five different sections: Home, Functions, Data, Tools and Documents. In the Functions section, all models can be accessed. All models are displayed as separate models, for which the input data and

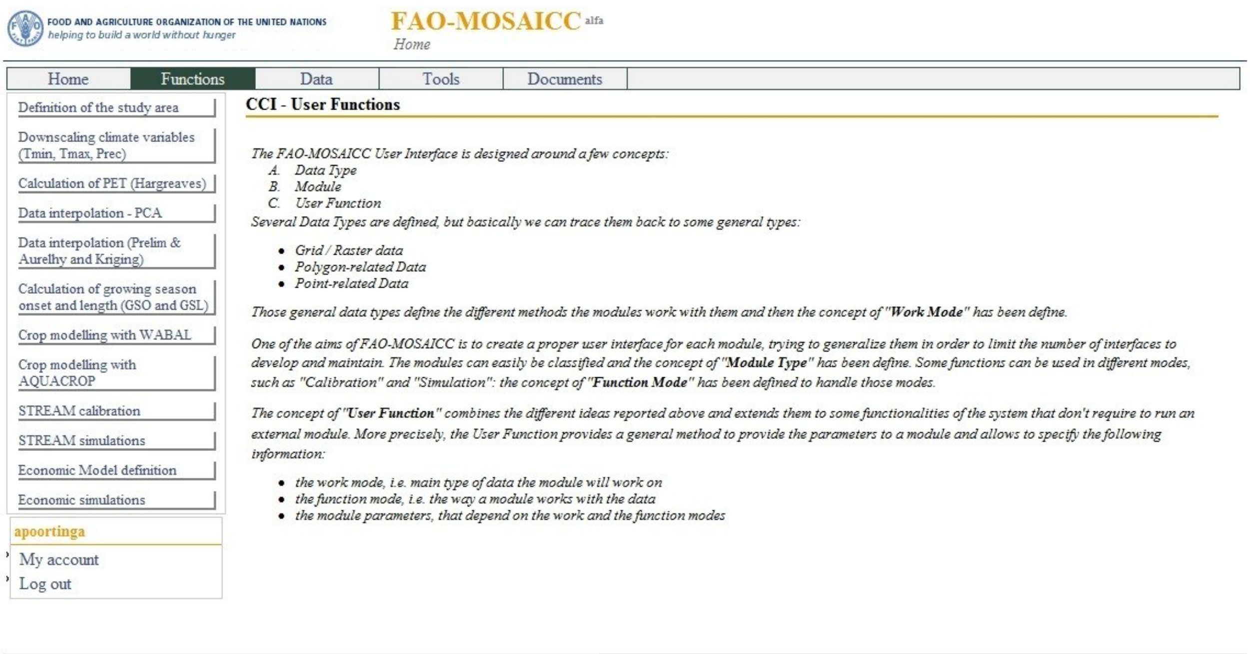

Figure 2: the web interface of the MOSAICC toolbox

parameters can be specified by browsing through different pages. Climate scenarios can be down- and up-scaled through space and time and calibrated with in situ data. After specifying all input data, the selected model can be run. The input and output data are stored on the server; they can be explored in the data section and subsequently be used as input for downstream models. All data are attached to a personal user profile and can be shared amongst different users. The Tools section contains information on all the past model runs. Furthermore, a document section is available, which contains information on all the models.

DISCUSSION

The MOSAICC toolbox is a complex project, because it assimilates different methodological approaches in a comprehensive manner. The inherent complexities originate from the social, physical and technical interactions which all have their own sources of uncertainty. From for example a modeler's perspective, very much is still open to question. For example, with regards the quality of the different models and how they simulate the real word situation in conditions that might even be beyond their range. A model's performance is dependent on many variables, such as quality of input data, model structure, calibration, validation etc. Insight into the model structure and the sensitivity to different parameters is of utmost importance to give a scientifically sound appraisal of the model output. But also the integration of the different models is a point of attention. Every model has its own spatio-temporal domain in which it performs best, and a mismatch between different spatio-temporal domains can result in an incorrect interpretation of the processes and results. However, these questions were raised and addressed at the beginning of the project.

Simple process based models were preferred above more complex models because of their generic nature. The models were selected because of their capacity to simplify the intrinsic complex nature

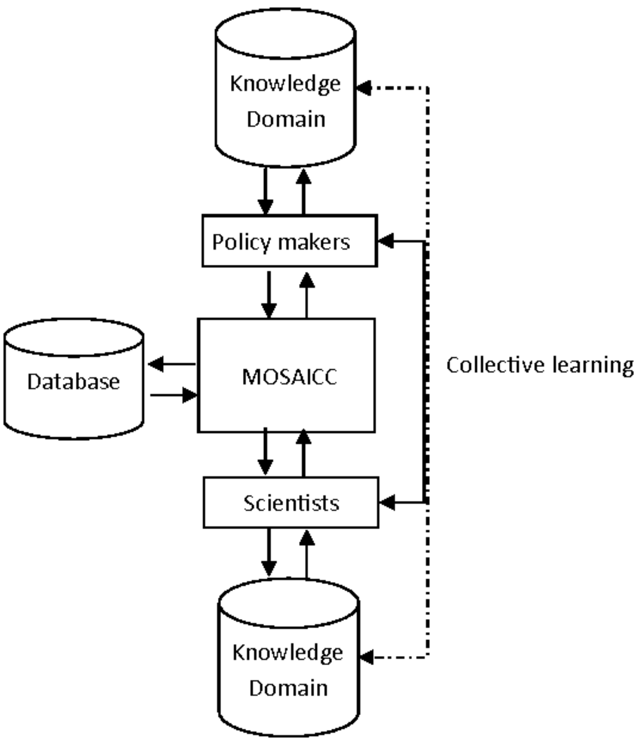

Figure 3: The collective learning process of the MOSAICC training program

transparent manner. The selected models and data are very well tested, documented and have proven their worth in exactly the type and scale of simulations that MOSAICC is targeting. The models are capable of handling low resolution data inputs, but can also handle data obtained from other sources (e.g. dynamic downscaling), due to their open nature. All models are able to give estimates and predictions on the spatial extent from a medium sized catchment to a country scale. Temporal resolutions can be defined in the range from weeks to years or even decades, where the effect of different temporal resolutions have not been tested yet. The main interest is towards trends on the longer time horizon of 30 – 100 years. The extensive FAO database with information on soil, land-use and historic yields are connected to the crop and hydrological modules in order to capture data gaps. However, testing is needed to validate if these independently generic, robust and flexible models provide the user with the required estimations and projections.

The overall project is an accumulation of different disciplines like technical IT consultancies, decision makers, scientists etc. This multidisciplinary approach has many risks, such as a mismatch in the assumptions of the different groups working on a project. For example, from a modeler's perspective, it is clear that a model is just a simplification of a real world situation with many assumptions, whereas policy makers depend on model projections in the decision making process, and do not necessarily take all these assumptions into consideration. The overall strength of the whole project should therefore be considered the search for a collective learning process (figure 3), as a model environment can only perform a problem solving role when it is enrolled in the interaction of multiple stakeholders (Sterk et al. 2009).

Natural scientists, and especially modelers, have specific knowledge on the physics of environmental processes. Policy makers on the other hand, hold contextual knowledge on a specific domain or geographic area. Both pools of knowledge are very important in case of an environmental appraisal or intervention. When scientists and policy makers work together in an interactive collective learning environment, this knowledge can be shared through a joint interface. Information can be stored and shared amongst different users in a central database. This platform of direct and indirect communication stimulates a two directional information flow, strengthening the mutual understanding of both stakeholders. The data from the database can subsequently be accessed by anyone at any time because of the web-based character of the toolbox. Because of the open character, students, local citizens or other stakeholders are also able to access the toolbox and contribute their own ideas and innovations. Where training of the end-users is a necessity to establish a minimum level of conceptual understanding, obtain the required it skills and understand the inner workings of the toolbox. However, the complexity of the models, interface or input and output data is the main threat for a decision support system (Carlo 2007).

Innovation in agro-environmental modeling approaches does not only concern the improvement of current modeling approaches, but also working on agile and versatile adaptive management support systems, in order to combine contextual information with domain-specific process based knowledge. From a participatory management perspective, it is important that different stakeholders involved in a problem analysis or decision making process have a common pool of knowledge. This common pool of knowledge can be used as an integral part in the decision making process, where all stakeholders have access to the same information for active participation in the decision process. Knowledge

CONCLUSION

The MOSAICC toolbox is not flawless from a scientific technical perspective. However, the goals of the project reach much further than a simple technical model integration. The MOSAICC toolbox is actually a very novel and innovative approach to develop, compare and evaluate the impact of climate change in an interactive way, where state-of-the-art technologies are used in a bottom up management strategy

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